9. *The SEMNA CATARACT or RAPID of the NILE: a STUDY in RIVER-EROSION.* By JOHN BALL, Ph.D., A.R.S.M., F.G.S., Assoc.M. Inst.C.E. (Read November 19th, 1902.)

[PLATES III & IV.]

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I. INTRODUCTORY.

OF the numerous ancient inscriptions discovered in Egypt by Lepsius during his expedition of 1842-1845, few were of a higher degree of interest than those on the rocks at Semna, between the Second and Third Cataracts of the Nile, which record the levels of high Nile in various years under the 12th and 13th dynasties. For, apart from their purely historical value as indicating the importance attached, even at that early age, to precise records of the river which has always been the life-stream of Egypt, these marks serve as a means of gauging the local changes which have taken place through the geological agency of river-erosion during a period of about 4200 years.

Lepsius spent 12 days at Semna and the neighbouring village of Kumna, and besides copying a large number of the inscriptions and making detailed plans of the two temples situated one on each side of the river, he made a sketch-plan of the rapid, and determined the fact that the high-Nile level indicated by the sculptured marks on the rocks is about 24 feet higher than the high Nile of our own day. The data published by Lepsius in his great work¹ were the subject of a careful consideration from the geological standpoint by a former president of the Geological Society, Horner, in 1850.² Horner, who does not appear to have himself visited the place, came to the conclusion that

‘the only hypotheses that could meet the requirements of the facts observed, would be either the wearing away of a reef or barrier at the place in question—a process requiring too long a period—or the existence at some distant period of a dam or barrier, formed perhaps by a landslip of the banks, at some narrow gorge in the river’s track below Semna, which in the course of time had again been washed away:—but of the existence of any such contraction of the channel where such a barrier was possible there is as yet no evidence The conditions attending these markings, at present so enigmatical, offer an interesting problem to any geologist, well versed in the questions of physical structure involved, who may hereafter visit Nubia.’

¹ ‘Denkmäler aus Ägypten & Äthiopien’ Leipzig, 1849-59, Abth. i, Bl. 111-113; Abth. ii, Bl. 139; Abth. iii, Bl. 47-67. See also Lepsius’s ‘Letters from Egypt’ p. 269.

² Quart. Journ. Geol. Soc. vol. vi (1850) p. 384. The paper is only published in abstract; I have been unable to consult the original manuscript, so as to examine Horner’s reasoning more fully.

Although abundant references to the markings, and the change of level which they indicate, are to be found in historical works published since Horner's day,¹ I have been unable to find that the question has been further investigated by geologists. It was evident that a solution of the problem could be expected only from a further careful examination of the locality; and it was therefore with peculiar satisfaction that I availed myself of the kind permission of Sir William Garstin, the Under-Secretary of State for Public Works, to visit Semna during the Bairam holiday of March 1902, and to publish the results of such examination as I could make there. I was in hope that after a careful survey of the Nile Valley at the place, combined with such data concerning the geology of Nile cataracts as I have been able to pick up during several years' investigation at other points, the enigmatical nature of the marks might disappear. This I believe is really the case; and I hope to show in the present paper that, owing to the structure of the district, a fall in the level of the river at Semna of the magnitude shown by the inscriptions is the natural consequence of such river-erosion as is going on at the present day, acting through the period of 4200 years indicated by the date of the markings.

II. TOPOGRAPHICAL DESCRIPTION OF THE DISTRICT.

Semna is not difficult of access from Wadi Halfa, from which it is about 43 miles distant. The train can be taken as far as Sarras, leaving only about $7\frac{1}{2}$ miles to be covered on camel or donkey, and the road is of a highly interesting character, from the variety of igneous and metamorphic rocks passed through. The route is shown on the Wadi-Halfa sheet (35, I) of the map of the Egyptian Sudan recently published by the War Office.² The small hamlet of Kumna, situated within the ruins of an ancient fortress, and inhabited by about 60 poverty-stricken but hospitable Nubians, makes the best halting-place; there are no inhabitants of the ruins of Semna, which lie on the opposite (western) bank.

Immediately above and below the Kumna and Semna temples, the river has a width of about 400 metres (1300 feet), but between the two temples a narrow band of hard red and grey gneiss forms a natural barrier across the stream. At high Nile the river flows over this barrier without any considerable diminution of its width, though, owing to the shallowness of its path and the irregularities of the gneiss-surface, its velocity is much increased and violent eddies are

¹ See, for instance, Prof. Maspero's 'Dawn of Civilization' 4th ed. (1901) p. 488, or Dr. Budge's 'Egypt under the Amenemhats & Hyksos' 1902, p. 46. Dr. Budge states that 'various explanations have been put forward of the extraordinary change which appears to have taken place in the level of the Nile between the time of Amenemhat III and our own, but none of them clears away all the difficulties in the matter.'

² I have followed the orthography of this map in the names of the two villages. They are, however, more usually spelled Semneh and Kummeh; and, from a Greek inscription cited by Prof. Maspero, in his 'Dawn of Civilization' 4th ed. (1901) p. 485, it would appear probable that Kumna is a more correct spelling than Kumna.

set up. At low Nile the gneiss-band entirely bars the stream, except for a narrow central channel about 40 metres (130 feet) in width.

The accompanying map and section (Pl. III), based on a rapid reconnaissance-survey, represent the condition of things at low Nile in the middle of March 1902. The shore-line and the rocky bar were surveyed with a 3-inch tacheometer; this portion of the map may, I believe, be relied on within the scale-limits. The village of Kumna was measured by pacing, aided by tacheometric fixation of its principal points. The hill-features away from the river, and the brick-ruins of Semna, are only roughly sketched in. Absolute levels were not taken, as this would have involved a long line of spirit-levelling from distant bench-marks. The relative levels shown were found tacheometrically, with untrained fellahin as staff-holders; they are believed to be accurate to within 0·2 metre (8 inches). The Assuân gauge-reading at the time of the survey was 1 pic 11 kirats, corresponding to the reduced level of 84·93 metres (279 feet), and a discharge past Assuân of 390 cubic metres (13,650 cubic feet) per second. There is so little water taken off between Semna and Assuân, that we may very fairly assume the discharge past the Semna barrier at the time of the survey to be about 400 cubic metres (14,000 cubic feet) per second. The whole of this discharge passed through the 40-metre central channel without any foaming, though the throttling of the entrance by rocky islets produced numerous eddy-currents; and the velocity of the narrow stream, as roughly estimated by the eye, was only about 4 kilometres ($2\frac{1}{2}$ miles) per hour, so that it was at once evident that the channel was deep. A sounding taken in the centre of the rapid gave the depth of water as 23 metres ($75\frac{1}{2}$ feet), but probably 3 metres (10 feet) or so should be taken off, to compensate for deflection of the plumb-line by the current. No soundings were taken outside the central channel; but there doubtless exists a great deepening down-stream of the barrier, due to the action of the water in falling over it. On both sides of the barrier the water was so placid as to resemble a lake more than a river. How great is the contrast between the flow across the bar and that on either side of it, will be evident from the sketch reproduced in fig. 1 (p. 68), which is taken from a photograph.

The ruined temples of Kumna and Semna, with their surrounding forts, lie on elevated portions of the same gneiss-band as that which forms the barrier, and the fissile gneiss has been used by the ancients to form embankments around their erections. The temples, as they now stand, date from the 18th dynasty; but the forts around them are considerably older, and appear to have marked the southern frontier of Egypt proper (not of the Empire) during the 12th and 13th dynasties¹: thus they formed an appropriate place for registering the height of the flood, which was important as information for the great irrigation-engineers of the time. A large

¹ Maspero's 'Dawn of Civilization' 4th ed. (1901) p. 485; also *id.* 'The Struggle of the Nations' pp. 89, 230.

Fig. 1.---*Rough sketch of the Senna Barrier on the Nile, as seen from the western bank.*

[The arrows show the direction of the stream through the narrow central channel. The ruins of Kumna are seen on the hill beyond the channel.]

number of such records, roughly sculptured on the gneiss-rocks below the temples, are to be seen. I localized and copied several of these on the Kumna side, and am indebted to Prof. Maspero, the Government Director-General of Antiquities, for the translation of the hieroglyphs. One inscription, situated 10·9 metres (36 feet) above the present high-Nile level, reads as follows:—

‘Level of the Nile of the year XXIII, under the majesty of King Nimaitra, Son of the Sun, Amenemhat, giving life, stability, wealth, like unto the Sun for ever and ever.’

A group of other inscriptions¹ of different years, in which the same formula is used, are situated just below the Kumna temple at an altitude of 7·9 metres (26 feet) above the present high-Nile level. It should be explained that, although I did not myself see the place when the Nile was in flood, yet there can be no doubt of the correctness of the differences of level noted, as the people of Kumna pointed out the precise spot where they go to get water at high Nile. My observation of the magnitude of the fall of the river between B.C. 2300 and the present day, thus confirms that of Lepsius.

It would appear to be no difficult matter to dam up the river by a filling of heavy blocks in the central channel, but I failed to find any evidence of the former existence of an artificial dam at the place, such as Sir W. Willcocks suggests² might have been built by Amenemhat.

III. GEOLOGY.

The rocks near the river are igneous and metamorphic for a considerable distance both up- and down-stream of Semna. They consist of granite, diorite, gneiss, and hornblende-schist, with dykes of porphyry and quartzite. West of Semna, at a distance of about a kilometre (5 furlongs) from the Nile, these rocks are overlain by Nubian Sandstone, forming the conspicuous hill called Jebel Barka. On the east side there is no Nubian Sandstone near the river, though Dr. W. F. Hume informs me that it exists farther east than I ventured to wander.

The Gneiss.

The rocky barrier which stretches across the stream between the two temples consists entirely of very hard red and grey gneiss, the foliation-planes of which strike parallel to the direction of the river (that is, north-eastward), and dip about 30° south-eastward. The foliation is extremely marked, the rock being very fissile in spite of its hardness, and the steeply-dipping foliation-planes form slippery slopes polished by the annual dragging over them of the countless tons of sand and silt brought down by the river. The portion of the barrier which is laid bare at low Nile is honeycombed with large potholes (fig. 2, p. 70), which attest the powerful grinding

¹ This group and the preceding inscription correspond, I find, with those figured as K and L respectively in pl. cxxxix of Lepsius's ‘Denkmäler’ (pt. ii).

² ‘Egyptian Irrigation’ 2nd ed. (1902) p. 30.

action of the stream in flood. Frequently a number of potholes cut one into the other, and masses of rock are thus detached which fall into the cavities and continue the grinding. The rocky bar is of course quite bare of debris, except for the boulders lodged in the numerous potholes and hollows; and even where the rock is untouched by the annual flood, it is of marked freshness, though

Fig. 2.—*Sketch showing potholing of the gneiss-barrier in the Nile, Semna Cataract.*

covered with separated blocks and flakes. Here, as in all arid regions, the process of weathering is mainly one of disintegration without decomposition, the great diurnal variation of temperature being the principal agent in the process. A small amount of chemical decomposition certainly goes on, but its products are removed by water or the sand-blast with great rapidity. The specific gravity of the gneiss is 2.61.

A microscopic examination of the rock shows it to be a highly-crushed biotite-granite, consisting almost entirely of quartz, orthoclase, and biotite, with very minute amounts of apatite, sphene, and iron-oxides. The usual evidences of crushing, in the shape of parallel disposition of the constituents, cracked crystals, cataclastic structure, and undulose extinction, are strongly marked. The variations of colour in the mass are due to variations in the relative abundance of pink orthoclase and dark biotite. The gneiss extends for some distance on either side of the barrier, but here appears to have been more highly crushed, and thus more easily eroded, than the band which forms the barrier itself.

The Syenite-Porphry.

Dykes of syenite-porphry are well defined in the gneiss, both on the left bank south of the Semna temple, and on the right bank in the hill behind Kumna. In the latter place the dykes are far from vertical, dipping steeply northward; on the eastern bank they are on gently sloping ground and the dip is not seen, but the strike is about east-south-east. On a fresh fracture, the rock is of an ashen-grey colour with a brownish tinge; it contains in places pink porphyritic crystals of felspar up to 3 millimetres in diameter, in a fine-grained grey groundmass. The exposed surfaces are of a rusty-brown; and where below the high-Nile level they are polished, so as to give the rock the appearance of eisenkiesel. The brown skin penetrates to a depth of about 1 centimetre, the limit between it and the normal grey rock being very sharply defined. The specific gravity of the porphyritic rock is 2·45. Examined microscopically (see Pl. IV, fig. 2), it is seen to consist mainly of felspar (orthoclase), of which there are two generations: the first in large porphyritic crystals, and the second, forming the bulk of the groundmass, in rod-shaped ones. Both classes of felspar are much kaolinized, but they are fresh enough to render their orthoclastic nature evident. There is a considerable amount of hæmatite in large irregular grains, often partly surrounding the felspars of the groundmass; and quartz is sparingly present.

The sections having been purposely cut to show the transition from the grey interior to the brown skin, the explanation of the formation of the latter is readily seen from them. In the internal portions, the hæmatite is in perfectly opaque grains, mostly of considerable size, and there is only a moderate sprinkling of smaller grains, so that the felspars, except for kaolinization, are clear. In the brown skin, the larger iron-oxide grains are translucent, of a red-brown colour; and strings of the same mineral extend through the groundmass between the felspar-crystals in all directions, while at the same time the felspars are themselves full of minute granules and strings of hæmatite and limonite (see Pl. IV, fig. 3). There has thus been brought about by hydrous action a migration of iron-oxides, from the separate clearly defined grains of the normal rock, into the substance of the felspathic groundmass. I am inclined to think that the large opaque hæmatite-grains of the normal rock are a product of oxidation of a ferromagnesian silicate, perhaps biotite. The well-known alteration of biotite with separation of large flakes of iron-oxide is strongly marked in rocks which I have examined from the First Cataract, where it can be seen in every stage. Here, however, not a vestige of biotite or hornblende remains.

The variety of the rock which is free from the pink porphyritic crystals is otherwise exactly the same as the one described, and shows the same process of migration of iron-oxides by water-action. Its specific gravity is, however, slightly higher (2·51).

The syenite-porphry dykes show less crushing than any of the other igneous rocks near them, and are probably the youngest igneous rocks in the district.

The Hornblende-Schist.

This rock forms a considerable patch on the left bank just above the Semna temple. The relations of this rock to the gneiss are not very clear, but it appears to form a band in the latter. In correspondence with its more basic composition, it is much more highly weathered than the gneiss, and forms a less prominent feature in the landscape. Its specific gravity is 2.96. Like the gneiss, this rock also proves on microscopic examination to be a deformed igneous rock, being in fact a somewhat crushed fine-grained diorite. Hornblende, the most abundant constituent, occurs in highly pleochroic, allotriomorphic crystals (pale yellow to deep blue-green, extinction-angle $c - c = 18^\circ$). The feldspars, which with the hornblende make up the bulk of the rock, appear to lie between andesine and labradorite, sections perpendicular to the brachypinacoid giving extinctions up to 25° . Very small amounts of quartz, and a brown biotite, the latter intergrown with the hornblende, are present; and there are a few idiomorphic crystals of apatite, as well as grains of hæmatite, epidote, and perhaps sphene. The microscopic slide here shows far less evidence of crushing than in the case of the gneiss: the schistose appearance is only well seen in the rock-mass. Hence it would appear likely that the rock represents an intrusion into the gneiss subsequent to the main crushing operation.

The Augite.

One of the specimens taken from what was thought in the field to be a more basic development of the 'hornblende-schist' above mentioned, proves on microscopic examination to be an augite of an interesting character. The rock, which is very fine-grained and dense (specific gravity = 3.24), is of a blackish-green in the mass. The thin section shows it to be holocrystalline, and to consist entirely of augite, hornblende, and sphene, with a small amount of interstitial quartz. The augite, which forms about five-sixths of the slide, and of which there is no trace of more than a single generation, is almost colourless, having only a faint brown tinge; it forms a mosaic of more or less rounded granules, with frequent irregular cracks and well-marked cleavages (see Pl. IV, fig. 1). Prismatic sections give extinction-angles up to 42° . Scattered through the augitic mosaic are irregular straggling crystals of green hornblende, and large granules of sphene; these last two occur in about equal abundance. The sphene, though mostly in rounded grains, is sometimes seen in approximately idiomorphic forms, being the only constituent of the rock to appear thus: the grains are about as large as those of the other minerals present, and show strong pleochroism (almost colourless to a rather deep pink-brown). The little quartz present is in the form of small interstitial grains, and is probably of secondary

origin, as the rock shows signs of a certain amount of crushing. Magnetite is entirely absent. The order of crystallization would appear to be (1) sphene, (2) augite, and (3) hornblende, as the last-named mineral frequently occupies interspaces around the augites. Unfortunately, as the exceptional nature of the rock was not recognized in the field, its relations to the associated gneiss and schist were not made out; it appeared, however, to form part of the basic intrusion which has been suggested as the origin of the schist, and thus to be younger than the gneiss.

Physical Geology.

To account for the deep central channel across the bar, I was at first inclined to believe in the existence of a soft basic dyke, such as accounts for most of the channels between the islands of the Assuân Cataract. But I failed to find any evidence of such a dyke, which would in fact have a strike perpendicular to that of the syenite-porphry veins already mentioned; and I believe this channel, like the parallel smaller channels which are only filled at high Nile, to be due to the simple erosive action of the river, the regularity being due to the coincidence of the direction of flow with the strike of the foliation-planes of the gneiss. It is obvious that at an early stage of the erosion some one channel would be slightly deeper than the rest, owing to accidental circumstances; and this deepest channel, conveying more silt-laden water than the others, would be more rapidly deepened.

The sketch-map published by Lepsius in his 'Denkmäler' (pt. i, sheet 3) was drawn in the latter half of the month of July, when the river would have risen considerably above its lowest level: the true nature of the rocky barrier is thus imperfectly exhibited, and at the same time the extent of the valley shown above and below the barrier was insufficient for a true judgment to be formed as to the manner in which the fall of the river-level had been brought about. From the survey just accomplished at low Nile, it will, I think, be easy to show that the explanation is to be sought in the wearing away of the barrier itself. Horner indeed put this forward as an hypothesis, but dismissed it as requiring too long a period of time. In thus dismissing it he was almost certainly wrong, for the barrier is of small extent, and the yearly removal of a comparatively small amount of it will explain the facts observed. It should be premised that relatively deep water exists both above and below the barrier, which is only about 200 metres (650 feet) in average width; and this condition of things, owing to the difference in hardness of the rocks, must have existed for long ages. Further, the enormous amount of potholing shows that by this means the river is rapidly breaking up the barrier, and that ordinary direct erosion plays a subordinate part.

The area of the barrier is approximately 500×200 or 100,000 square metres. Taking the lowest group of ancient inscriptions of the time of Amenemhat III above mentioned, as marking the average high Nile of the period about 2300 B.C., we have a vertical erosion

of 7.9 metres in 4200 years, or nearly 2 millimetres per year, to account for. Such erosion corresponds to $\frac{2 \times 100,000}{1000}$ or 200 cubic metres of rock, weighing approximately 500 tons, per year.

The amount of rock removed by simple solution in the stream during 4200 years must in itself be considerable; but it is impossible of accurate estimation, and is probably so insignificant in comparison with that removed by mechanical action, that we may neglect it in the following consideration.

The yearly discharge of the Nile past Semna is very nearly 100,000 million tons of water, at a mean velocity of $4\frac{1}{2}$ kilometres per hour at high Nile and $2\frac{1}{2}$ kilometres per hour at low Nile; and it should be remembered that these velocities, which in themselves are capable of accounting for the sweeping along of large pebbles, are locally so much increased by the numerous rocky obstructions as to permit of the movement of boulders and rock-fragments bigger than a man's head. Further, quite apart from the pebbles and boulders which are swept over the barrier and dropped in the deeper water beyond, the quantity of fine silt or rock-flour carried by the stream is certainly not less than 60 million tons per year.¹ And, finally, one must not lose sight of the circumstance, that the strike of the foliation-planes of the gneiss is parallel to the direction of the current, and thus most favourable to the creation of channels across the barrier.

When the foregoing facts are borne in mind, the removal of 500 tons of rock per year under the existing conditions is not only not impossible, but highly probable. Thus such an amount of erosion corresponds to the removal of only $\frac{500 \times 100,000}{100,000,000,000}$ or 5 milligrammes of rock, per ton of silt-laden water. Or, looking at the matter another way, the potholing action certainly accounts for at least two-thirds of the action, leaving, let us say, 170 tons to be accounted for by the action of the fine silt: this only corresponds to $\frac{170 \times 1000,000}{60,000,000}$ or about 3 grammes of rock per ton of fine silt swept over the barrier.

The rate of erosion demanded by this simple explanation of the facts observed is, moreover, not greater than that which would be suggested by a comparison of measurements of river-erosion made in

¹ The average flow past Assuân is given by Sir W. Willcocks ('Egyptian Irrigation') as 2990 cubic metres per second, or 94,292 million tons per year. At Semna it will, of course, be in excess of this, as some water is taken up by evaporation and irrigation between Semna and Assuân.

The most reliable data as to the amount of silt carried in suspension by the Nile are those obtained by Dr. Mackenzie, Principal of the School of Agriculture at Giza, and published in the Public Works Administration Reports for 1896 (p. 43) & 1898 (p. 101). From the mean of monthly determinations extending over three years, the amount of silt carried past Cairo is 57 parts in 100,000 of water. This gives $\frac{57 \times 100,000,000,000}{100,000}$ or 57 million tons per year.

Bearing in mind the thick deposits which are thrown down on the lands of Upper Egypt, the quantity of silt passing Semna must be considerably over 60 million tons per year.

other districts. To quote a single well-known case, the River Simeto, flowing through the Etna lava-stream of 1603, had by 1828 cut for itself a passage from 50 to several hundred feet wide, and in some parts from 40 to 50 feet deep.¹ There is doubtless a considerable difference between such lava and the Semna gneiss in point of hardness; but even when due allowance has been made for this fact, the comparison is not unfavourable for the truth of the explanation suggested. Nor can it be objected that the evidence at other points of the Nile Valley is in any way contradictory. It must be borne in mind that, except at the cataracts, the processes of erosion and deposition of silt in the Egyptian portion of the valley of the Nile nearly balance each other; while at the cataracts the action is purely erosive, and in fact corresponds more to that of a mountain-stream than to that of a peacefully-flowing river.

A study of the Semna rapid, which may be taken as the simplest possible case of a Nile cataract, throws considerable light on the study of more complex cases. All the Nile cataracts exist at points where igneous and metamorphic masses crop out through the softer sedimentary rocks, and are the consequence of the greater difficulty which the river finds in eroding a course through such masses. We are still far from having sufficient information, concerning these interesting features of the great Egyptian river, to be able completely to trace its past history as a geological agent; but my own researches at the Assuân Cataract, and those of my colleague Dr. W. F. Hume at the higher ones, have brought to light a number of very striking facts, more especially concerning the influence of dykes and faults in determining the river's course, and there is ground for hope, that when all the observations have been worked out and co-ordinated, a very considerable advance in the study of the problem will have been made. At Assuân and Silsila the river has entirely changed its channel and suffered a considerable lowering² within geologically recent times, though before the historical period; and it is probable that such changes were largely brought about by the removal of long pre-existent hard barriers such as the one at Semna. There can be no doubt that at all these cataracts erosion is very rapidly going on, though masked from observation by the absence of records of sufficient antiquity and by the great variations in the floods of different years. At Silsila and at Kalabsha in Lower Nubia, the river passes rapidly through narrow gorges in hard rocks; and when soundings and borings were taken there a few years ago for the proposed reservoir-dams, it was found that the bottom of the stream, far from being, as was expected, solid rock, was in fact in each case composed of sand to a depth of over 20 metres.³ It is impossible to explain the existence of this thick sand-stratum, unless we assume

¹ Lyell, 'Principles of Geology' 11th ed. (1872) vol. i, pp. 352-53.

² My own observations give the fall at Assuân as at least 20 metres (65 feet), while Prof. Schweinfurth gives that at Silsila as 20 to 22 metres, Petermann's *Mitth.* vol. xlvii (1901) p. 9. If, in these cases, the lowering of the stream has proceeded at a rate similar to that recorded at Semna, the period corresponding to the changes is about 10,000 years.

³ For this information I am indebted to Mr. Marshall Hewat, who conducted the borings in question for the Egyptian Government.

that there formerly existed barriers at these places, the fall of water over which would cause a great deepening of the channel on the down-stream side, and as the barrier was gradually worn back the local deepening of the channel would become filled with silt.

Surprisingly deep soundings have been taken quite recently below the new reservoir-dam at the Assuân Cataract, and these again can only be explained on a like assumption. Thus it would appear that, after allowing for the well-known tendency to gross exaggeration in early 'travellers' tales,' there may have been some foundation for the statements of numerous classical writers,¹ who describe the Assuân Cataract as a distinct waterfall, tumbling over a precipice with a loud noise; more especially if they relied on a tradition handed down from earlier times, rather than on the evidence of an eye-witness of their own day. Finally, the fact that the whole of the cultivated lands of Lower Nubia, and the large alluvial tract which forms the Kom Ombo plain, lie at so great an elevation as to be impossible of irrigation at the present day without the aid of water-raising appliances, is easily explained by the hypothesis that, at Silsila and Assuân at least, the river was formerly dammed back by natural obstructions which have since been eroded away.

A very good site for a quantitative determination of the rate of erosion in granite by the silt-laden waters of the Nile will be furnished by the sluices of the new dam at Assuân. In this case all large stones will be kept out by grids, so that only the smaller pebbles and sand will be carried through, and some years will doubtless have to elapse before the erosion has proceeded sufficiently for a reliable measurement to be obtained. And with regard to the rate at which potholing action is removing the barrier at Semna, it would appear not difficult to make a fairly accurate experimental determination within a few years, for the action is certainly a relatively rapid one, and the holes are laid dry regularly every year at low Nile.² It would be easy to mark a few average holes, and after temporarily removing their contents, to measure their transverse dimensions and their depths below artificial datum-marks deeply sculptured in the sides of the holes; if then the stones were replaced within the holes exactly as found, and the action allowed to go on for a few years, a remeasurement would indicate the average

¹ Diodorus Siculus, *Hist.* l. i, c. 3; Strabo, *Geog.* l. xvii, c. 1, § 49; Pomponius Mela, *De situ orbis* lib. 1, c. 9; Seneca, *Nat. Quæst.* l. iv, c. 2.

² That potholing may, under certain favourable conditions, proceed at such a rate as to permit of easy measurement after a few years' action, is proved by an observation in Sweden, recorded by Axel Erdmann ('*Bidrag till Kännedomen om Sveriges kvartära Bildningar*' *Sver. geol. Undersökn. ser. C*, No. 1, 1868, p. 82). About 1858, when the Oena paper-mills were built on the western bank of the Göta Elf, near the falls of Trollhättan, the required water for driving the mills was conducted from the river through a channel, which was at the time blasted entirely out of the rock. When an extension of the mills took place some 8 or 9 years later, it became necessary to widen this channel, for which purpose the water was drained off. It was then found that three small potholes had been formed in the bottom of the channel, of a maximum depth of 1½ feet, and of diameters varying from 6 to 12 inches, with the rounded pebbles (of trap) still remaining within them. Thus 8 or 9 years had been a sufficient time for the formation of these potholes, through the rotating motion given to the stones by the water flowing through the channel.

rate of enlargement. Then, by roughly counting the holes and multiplying, a very fair idea of the total amount of rock removed per year by such action would be obtained. I trust later on to find an opportunity of making such observations, time for which failed on my last visit, and thus to confirm or otherwise the view which I have expressed above,—that the lowering of the high-Nile level observed between B.C. 2300 and the present day, is a simple consequence of the operation, through the period of 4200 years, of that erosive action which is going on in our own times.

EXPLANATION OF THE PLATES.

PLATE III.

Map and section of the Nile Valley at the Semna Cataract on the scale of $\frac{1}{10000}$.
[The distance to Sarras on the map is misprinted as '72' instead of 12 kilometres, or $7\frac{1}{2}$ miles.]

PLATE IV.

- Fig. 1. Augitite from Semna, $\times 45$. *a*, augite; *h*, hornblende; *s*, sphene; *q*, interstitial quartz. (See p. 72.)
2. Syenite-porphry from Semna, normal form of the rock, $\times 40$. *p*=portion of a porphyritic orthoclase-crystal, with peripheral hematite-grains; *o*=orthoclase of groundmass; *q*=quartz; the dark masses are hematite, perhaps an alteration-product of biotite. (See p. 71.)
3. The same rock: outer crust, showing redistribution of iron-oxides, $\times 40$. The minerals bear the same letters as in fig. 2.

DISCUSSION.

Sir ARCHIBALD GEIKIE remarked on the value of observations which in any degree helped to furnish numerical measurements of the rate of geological changes. The data supplied by the Author appeared to be trustworthy, and to justify the inference which he drew from them. They showed a comparatively rapid erosion at that particular contracted part of the Nile. Though it might not be safe to conclude that the conditions of this erosion had been for a long time as they are now, it was at least an important point to obtain an average rate of denudation during so long a period as that which seemed to be indicated by the ancient Egyptian marks of water-level.

Prof. SOLLAS remarked that this was an interesting contribution to the history of the Nile Valley, and that the measurements made by the Author would afford useful data for subsequent observers. While evidence was obtained of the total erosion produced during a given period, no conclusions could be drawn as to a yearly rate, unless it were assumed that both the volume of the Nile and the slope of its channel had remained constant for the past 4000 years. It would be of interest to know whether the ancient records referred to an average, or to an unusual, high Nile.

Prof. HULL thought that the Author's observations would have been of more value if he had taken into consideration the changes in the physical conditions of the Nile Valley which may have had influence upon the rate of erosion at the Cataract. No problem of this kind could be solved without recognizing the former much

larger volume of the river, and the submergence of the Nile Valley to the extent of 200 feet below its present level, as shown by the raised beach at Mokattam above Cairo.

Mr. MARR asked whether there was any mention of joints in the paper. In an ordinary flowing river, the rock on the sides of joints passing from bank to bank could not be eroded more rapidly than the rock down stream, but in the case of waterfalls this was changed. Erosion was much more rapid along the joint-planes than along the intervening solid rock, and thus waterfalls usually bifurcated or split into even more numerous branches. As erosion proceeded along the dominant joints, the minor fissures became channels in wet weather only, and were at last deserted by the stream, so that ultimately the stream was confined to a channel along a dominant joint-plane, producing an effect such as that shown in the Author's plan. It must, therefore, be borne in mind that other factors than increased velocity of stream, as for instance the excessive erosion along joint-planes, must be taken into account in comparing the rate of erosion at falls with that in ordinary parts of a river's course.

Prof. GROOM asked whether there was any evidence that tectonic movements had had an effect on the conformation of this part of the Nile Valley, and whether some of the differences in the depth of particular parts of the channel might not be due to this cause.

Prof. JENN (in the absence of the Author) thanked the Society for the kind manner in which they had received the paper. He felt sure that it would be a great encouragement and incentive to future work, both to the Author and to his colleagues upon the Geological Survey of Egypt. In reply to Mr. Marr he stated that the Author found in the foliation, rather than in the jointing of the rock, those points of weakness that were favourable to excessive 'pot-holing' and erosion. The speaker recalled the papers on the subject published by the Society during the early years of its history, and stated that shortly before Sir Charles Lyell's death, he had visited with the veteran geologist the places where mason's marks had been made by Sir Charles when quite young, in the hope of determining the amount of erosion by rivers. Considerable erosion had taken place in the course of fifty years, but the mason's marks were not altogether obliterated.

POSTSCRIPT TO DISCUSSION.

[In reply to Prof. Sollas, the Author observes that there are a large number of high-Nile marks dated in the different years of Amenemhat's reign, and the inscription selected in the calculation of the erosion is one of the lowest of them; so that it may be taken to represent fairly an average, and not an exceptional, high Nile of the period. Although it is certain that the volume of the Nile was formerly greater than at present, there is no evidence that any very considerable change of volume has taken place within historical times. The changes at Assuân and Silsila are proved, by the positions of numerous inscriptions, to have occurred before the dynastic period; and though the river is of course gradually

(LOWER NUBIA)

by

Scale $\frac{1}{\text{cm}}$

I.

X 45.

II. III.

X 40.

AUGITE AND SYENITE-PORPHYRY FROM SEMNA.

J. Ball, del.

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flattening the inclination of its channel, the situations of numerous temples along its course are such as to prove the change to be a very slow one. Moreover, the rapid of Semna lies between the Second and Third Cataracts, where a similar, though perhaps slower, erosion is going on; and the average inclination of the river between them would remain constant if, as is probable, the rates of erosion at the upper and lower cataracts were approximately equal. Thus, while it is not possible to assert that the volume and inclination of the stream have remained constant for 4000 years, there is a strong probability that the change in these factors has been comparatively small in the given time.

The submersion of the lower part of the Nile Valley, as shown by raised beaches above Cairo, is, as Prof. Hull remarks, of very great importance in any consideration of the early history of the river. But the fact of the existence of the city of Memphis (the ruins of which are still to be seen near Cairo) for over a thousand years before Amenemhat's time, is sufficient to prove that the deposits referred to long antedate the historical period, and thus they indicate nothing as bearing on the question of erosion within the last 4000 years.

With respect to the question raised by Mr. Marr, I would only add to what has been stated in the paper, that in the minor channels, left dry at the time of my visit, I saw but little evidence of joints cutting across the foliation-planes; and thus, although it is quite possible that the position of the main channel may have been primarily determined by a joint or fissure, I was led to conclude that it, like the others, was conditioned simply by the foliation-planes, which themselves are planes of weakness. Joints and crush-planes perpendicular to the foliation-planes are of great frequency in the gneisses and schists immediately above Assuân, where they account for most of the 'khors' or side-valleys opening to the river; but they are less abundant near Semna, and, as I have said, not evident at all in the rocky barrier itself.

With regard to Prof. Groom's question concerning tectonic movements, it is certain that large portions of the Nile Valley have been subjected to such changes. But a great deal of work remains to be done before the nature and extent of such movements can be even approximately determined; all the evidences that I have yet been able to examine tend to show that the tectonic movements, like the climatic changes, ceased long before the historical period with which my paper is more immediately concerned.

Thus I consider that the change which has undoubtedly taken place at Semna within the last 4200 years cannot be explained as due to any change in the discharge or general inclination of the river, nor to fissures, nor to tectonic movements, nor, in fact, to anything but simple erosion at a very rapid rate owing to the local contraction of its channel.—J. B., *December 9th, 1902.*]